Factors Influencing Occurrence, Scale, Mobility, Runout, and Morphology of Mass Movements on the Continental Slope

Homa J. Lee
U.S. Geological Survey, M/S999, 345 Middlefield Road
Menlo Park, CA 94025
650-329-5485 (phone) 650-329-5411 (fax) homa@octopus.wr.usgs.gov

Award Number: N00014-97-F-0035
http://marine.usgs.gov/fy2000/cmg-research2000.html

Thrust Category: Marine Geotechnics

LONG-TERM GOAL

Achieve an improved understanding of the relationships between sedimentation, environment, and the morphology of continental slopes. This goal will be accomplished primarily through investigations within the northern California (Eel River) study area and incorporation of data from around the World. An underlying assumption of our work is that the occurrence and morphology of mass movement features on the continental slope depend upon a combination of characteristics, each of which varies over the region in a consistent manner. The various components of this project are part of a concerted effort between the geotechnical groups at the USGS and Laval University. Their activities are very much interwoven but, for administrative reasons, their respective budgets are identified separately, as are the annual reports.

OBJECTIVES

Identify factors that can be mapped regionally and that determine where and how slope failures occur; derive a basis for producing regional maps that indicate relative landslide susceptibility. Model shear strength development with depth and incorporate this model into continental slope stability, post-failure behavior, and bedform processes. Observe and model pore pressure development in continental slopes. Analyze the relationship between seismic intensity, sediment instability and slope processes.

APPROACH

Our research focuses on the factors that lead to variations in the sedimentological and environmental conditions determining slope failure. We develop improved correlations between engineering classifications and strength factors. We measure excess pore water pressures *in situ*. We simulate sediment accumulation in specially designed cells. Geotechnical properties are related to sediment density state, obtained from detailed logs of downcore variability of sediment density and sound velocity. Using available bathymetry, we construct slope maps. Seismic shaking variations are evaluated probabilistically by seismologists. *In situ* pore pressures are determined by means of the Excalibur probe (AGC-Atlantic). These pressures can be generated if the sedimentation rate is particularly rapid, if there is charging by bubble-phase gas, or if earthquake shaking disrupts the sediment fabric and causes it to collapse with a resulting increase in the pressure of interstitial fluids. Driving stresses are balanced against strength in a geographic Information System (GIS) to obtain a regional estimate of relative slope stability.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2000**	2. REPORT TYPE	3. DATES COVERED **00-00-2000 to 00-00-2000**
4. TITLE AND SUBTITLE **Factors Influencing Occurrence, Scale, Mobility, Runout, and Morphology of Mass Movements on the Continental Slope**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Geological Survey, M/S999, 345 Middlefield Road,,Menlo Park,,CA,94025**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Key individuals, at USGS: Homa Lee, Kevin Orzech, Diane Minasian, Peter Dartnell, and Florence Wong: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS; at Laval: Jacques Locat, Jean-Marie Konrad, Serge Leroueil, and Priscilla Desgagnész: strength and compressibility measurements, SEM studies, and rheology measurements, and simulation of sediment accumulation.

WORK COMPLETED

In FY00, we continued our development of a GIS-based approach toward regional assessment of offshore landslides. We have produced a map, based on sediment distribution, slope steepness, and anticipated seismic shaking, that shows a predicted measure of slope stability for the Eel margin (Fig. 1). To expand the applicability of our results, we are conducting a comparative study of the Los Angeles Margin using data obtained by Lee as part of a sediment pollutant transport study. We have

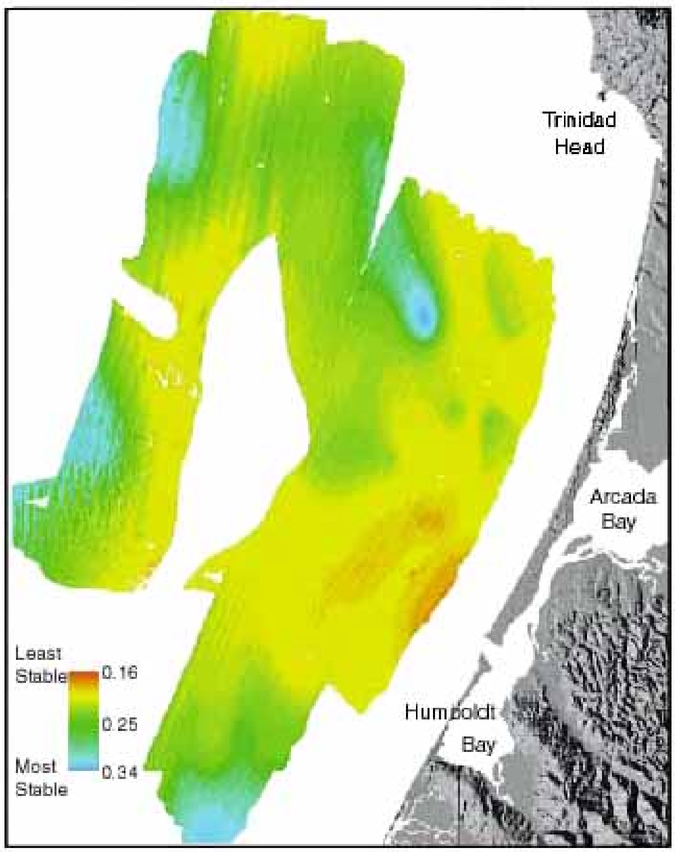

Figure 1. Prediction of relative slope stability for the Eel margin based on a GIS analysis of slope steepness, anticipated seismic shaking, and sediment characteristics. Warmer colors correspond to greater likelihood of slope failure.

prepared a map of the Los Angeles margin that shows the distribution of relative slope stability (Fig. 2). These studies are valuable because the Los Angeles margin shows a much broader distribution of slope failure features and the set of available data is as extensive as that from the Eel Margin. A paper

comparing our methodology as applied to both the Eel and Los Angeles margins was presented at the International Symposium on Landslides in Cardiff, Wales. We are also developing a more fundamental

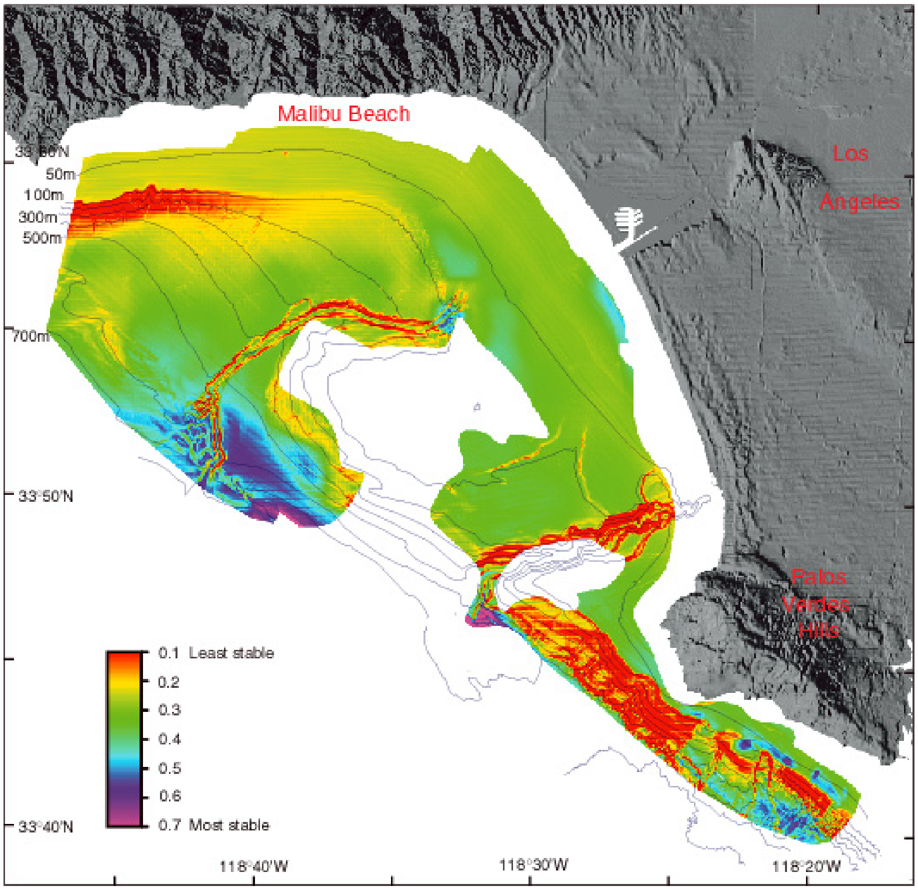

Figure 2. Prediction of relative slope stability for the Los Angeles margin based on a GIS analysis of slope steepness, anticipated seismic shaking, and sediment characteristics. Warmer colors correspond to greater likelihood of slope failure.

relationship between landslide occurrence and sediment lithology. In the past we have relied upon surficial sediment density as a measure of lithology. We are expanding our correlations to include engineering classifications that are not impacted by consolidation state.

We are continuing to test cores taken on the New Jersey Margin area from the Marion Dufresne cruise. A total of 3 long cores were collected (MD9922-11, 12, and 13), of which one is kept at Laval and is to be shared with the USGS group for various geotechnical tests. All cores were logged, onboard the ship, at 1-cm resolution for density, sound velocity, and magnetic susceptibility. We are also using a laboratory simulation to determine how significant repeated seismic shaking is gradually increasing the strength of marine sediment on slopes.

We are collaborating with Syvitski, Parker, Garcia, Orange, and Locat in recognizing and interpreting migrating sediment waves. We feel that these features are common along continental margins and that they are frequently misinterpreted as submarine landslides. We are developing criteria for recognizing these features and applying numerical and physical models to understand the mechanics of their development. We are preparing a paper for a special issue of Marine Geology that deals with migrating

sediment waves. The paper will include empirical, theoretical, and laboratory results that show the mechanism of formation of these features and illustrate the ways to distinguish these features from submarine slope failures.

RESULTS

Classic slope failure features on the Eel Margin are rare even though our methodology shows a high vulnerability to slope failure during seismic loading, indicating either that mass wasting on the Eel Margin takes unexpected forms or that mass wasting is less significant than would be expected. Shallow-seated failures are more common on the Los Angeles Margin. Our methodology shows even higher vulnerability to slope failure in Los Angeles Margin areas experiencing numerous shallow-seated failures. Our methodology shows promise in terms of delineating the environmental conditions that are conducive to shallow-seated submarine slope failure.

In collaboration with Laval, analyses of reconstituted specimens of Eel river sediment have been subjected to drained cyclic loading. Under conditions comparable to a series of earthquakes, we have found that the undrained shear strength increases significantly.

IMPACT/APPLICATION

Relationships developed in this project show the importance of sediment liquidity index and seabed density profiles in representing the behavior of marine sediment. These values can be used to predict regional slope stability and the rheological behavior of debris flows. This project shows the value of GIS techniques in combining the impact of a variety of marine sediment and environmental factors to yield information about a predicted outcome, in this case, susceptibility to slope failure. General strength-density relations can be used for modeling sediment accumulation and stability.

TRANSITIONS

Geoacoustic properties are being used by mappers and acousticians to identify lithologies acoustically. Rheological properties are being used by modelers to represent debris flows. Landslide generation models are being used by landscape evolution modelers.

RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin using many of the same techniques produced by STRATAFORM. Locat is investigating the behavior of a newly formed sediment layer acting as a natural cap over contaminated sediment in Canada. Locat, Lee, and a group of Canadian scientists and engineers have developed a project to collaborate with the European COSTA (COntinental Slope STAbility) project. This will allow us to verify in other environments many of the concepts developed with STRATAFORM support.

PUBLICATIONS

Desgagnés, P., Locat, J., Lee, H., Leroueil, S., and Alexander, C. 2000. Geotechnical Properties of a Mass Flow Deposit on the Hudson Apron, off New Jersey, U.S.A.. 53e Canadian Geotechnical Conference, Montréal, October, in press.

Imran, J., Parker, G., Locat, J., and Lee, H., 2000. A 1-D numerical model on muddy subaqueous and subaerial debris flows. Submitted to ASCE Journal of Hydraulic Engineering.

Lee, H.A., Locat, J., Dartnell, P., Israel, K., and Wong, F., 1999. Regional variability of slope stability: application to the Eel Margin, California. Marine Geology, 154: 305-322.

Lee, H.J., Locat, J., Dartnell, P., Minasian, D., and Wong, F., 2000. A GIS-based regional analysis of the potential for shallow-seated submarine slope failure. Proceedings, 8th International Symposium on Landslides, Cardiff, England, v. 2, p. 913-922.

Locat, J., Lee, H., and Locat, P., 2000. Analysis of Submarine Mass Movements and its Implication for the Generation of Tsunamis, with a Particular Reference to the Palos Verdes Slide, California. In: Proceedings of the Workshop on the Prediction of Underwater Landslide and Slump Occurrence and Tsunami Hazards off Southern California, Los Angeles, March 10-11 2000, In Press.

Locat, J. Lee. H.J., Kayen, R., Israel, K., Savoie, M.-C., and Boulanger, É., 2000. Shear strength development with burial in recent Eel River Margin slope sediments. Submitted to: Marine Geotechnology and Resources.

Locat, J., and Lee, H.J., 2000. Submarine landslides: advances and challenges. Keynote presentation, 8th International Symposium on Landslides, Cardiff, U.K., 30 p., In press.

Locat, J., Mayer, L., Gardner, J., Lee, H., Kammerer, E., and Doucet, N., 1999. The use of multibeam surveys for submarine landslide investigations. Invited Article. International Symposium on: Slope Stability Engineering: Geotechnical and Geoenvironmental Aspects, Shikoku, Japan, 8 p., in press.